



An extension to the methodology for characterization of thermal properties of thin solid samples by photoacoustic techniques



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ABSTRACT

The paper presents a study of possibilities to extend the present methodology for thermal characterization of thin solid samples by photoacoustic techniques. The present methodology consists of linear fitting of the experimental data to approximate the expressions derived from the composite piston model of photoacoustic response and it is mainly used for calculation of thermal diffusivity of thin samples. The study has shown that the methodology may be extended to calculation of thermal diffusivity, thermal conductivity and thermal expansion coefficients of thin samples by linear fitting in multiple frequency ranges and by analysis of the intersection frequency, which is the frequency where the magnitudes of two components of photoacoustic response in the composite piston model are equal. The analysis of numeric errors of the methodology has revealed the dominant sources and magnitude of the errors, leading to the conclusion that photoacoustic techniques should be carefully used as a tool for extensive thermal characterization of thin samples in the cases when other techniques are not applicable or have larger errors.

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1. Introduction

As non-contact and non-destructive material characterization methods, photoacoustic techniques have been used for thermal characterization of thin samples for four decades [1–12]. While photoacoustic techniques were mainly used for calculation of thermal diffusivity of samples [5–12], their application to calculation of thermal conductivity [10–12] and thermal expansion coefficient [13] of samples increases.

The photoacoustic (PA) effect, which is the basis for PA techniques, is generation of sound waves in a sample and its surroundings due to the exposure to modulated optical radiation [2–4]. The usual method for thermal characterization of materials is based on studies of dependencies of the amplitude (amplitude-frequency characteristics, abbreviated as AFC) and the phase delay (phase-frequency characteristics, abbreviated as PFC) of the PA response on the modulation frequency of excitation. The calculation of thermal and thermoelastic properties of the samples based on the experimental AFC and PFC represents “the inverse photoacoustic problem”. The methodologies for solution of the inverse

photoacoustic problem depend on the theoretical models of the PA effect, which are in turn determined by the setup of a PA experiment.

The PA effect was discovered and reported by A.G. Bell at the end of the 19th century [14], but the proper explanation was given in the 1970s in some papers of A. Rosenzweig [15–18]. The papers introduced the basic setup of the gas-microphone PA experiment and proposed a theoretical model of the PA effect called “the thermal piston model” [17]. The model considers the indirect mechanism of the PA effect [2], where the optically generated heat in the sample is transferred to the surroundings causing an increase in the temperature and expansion of the nearby gas. In the explanation of the indirect PA mechanism, a thin layer of the expanded gas adjacent to the surface of the sample acts as a “thermal piston” that generates sound waves propagating through the gas in the PA cell. In the reflection configuration of the PA experiment, when the light source and the microphone are placed at the same side of the sample, the thermal piston model successfully explains the PA effect [2,19].

However, during the 1980s, it was demonstrated that the transmission configuration of the PA experiment where the light source and the microphone are placed at the opposite sides of the sample offers many advantages [5]. In the transmission

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